SOIL PH MAPS DERIVED FROM ON-THE-GO PH-MEASUREMENTS AS BASIS FOR VARIABLE LIME APPLICATION UNDER GERMAN CONDITIONS: CONCEPT DEVELOPMENT AND EVALUATION IN FIELD TRIALS

H.-W. Olfs, A. Borchert, and D. Trautz

Faculty of Agricultural Sciences, Crop Production and Plant Nutrition
University of Applied Sciences Osnabrueck
Am Kruempel 31, D-49090 Osnabrueck, Germany

ABSTRACT

The huge impact of soil pH on soil characteristics and on nutrient availability in particular as well as on plant growth in general is well documented. As known for other soil parameters it can be expected that also for soil pH substantial in-field variability exists. However, due to time constraints for manual soil sampling and related costs for analysing huge amounts of samples in the lab the required density of soil pH measurements per field cannot be achieved. In the US a fully automated on-the-go soil pH mapping system (Veris MSP) has been developed to obtain spatial information on soil pH. This pH sensing system was adapted to German farm technology and validated under German soil and weather conditions.

On 30 arable fields (2 to 45 ha; sandy to loamy soil texture) located in north-western Germany pH online measurements were conducted using the Veris MSP equipped with a pH and an EC unit (working speed 5 - 13 km/h; spacing between passes 7.5 - 30 m; sampling density 30 - 90 samples per hectare). Reference samples were collected from the topsoil layer in zones with low, medium and high pH values. Based on these reference samples for 17 selected fields the relationship between Veris MSP and lab data was assessed by regression analysis. The subsequent transformation of Veris MSP pH values into German standard pH values was either done based on pH data from all 17 study fields or by only taking the three reference samples from each individual field into account. Finally a lime application field experiment in maize was conducted. Using Veris MSP data five zones were identified with different pH status and in each zone three treatments were installed: no lime, lime rate based on field average or adjusted to the pH in the specific zone. Leaf nutrient concentrations were analysed at tasseling. After harvest soil samples were taken (0 - 30 cm) in each plot for pH determination.

For many fields substantial in-field variability for soil pH was measured irrespective of the field size indicating that adaptation of liming rates within a field seems reasonable. Agreement between Veris MSP and pH values comparable to the German standard procedure after transformation was considerably better when based on the 3 individual reference samples for a field than using the complete data set (mean difference 0.08 vs. 0.26 pH units). On average liming strategy influenced nutrient concentrations in maize leaves at tasseling growth stage only marginal (exception for Mn and Zn which showed significantly higher values in the no lime treatment). As expected both liming strategies resulted in higher soil pH values on average. However, pH variability between the 5 subplots was much lower for the site-specific adapted liming treatment (pH range 5.9 - 6.1 vs. 5.6 - 6.2 for the “field average lime rate”), indicating that this strategy leads to a more homogeneous soil pH.

Keywords: in-field variability, precision lime application, reference samples, soil pH mapping, Veris MSP

INTRODUCTION

It is expected that world population will expand to about 9 Billion people during the next decades (UN, 2004), which will lead to a substantial decline in land area available for food production per person and consequently output per unit area must be increased. Besides water availability, adequate crop protection measures and sufficient nutrient supply, physical and chemical soil conditions (e.g. texture, pH) are most important to enable crops to fully utilize their yield potential.

Most arable crops prefer a nearly neutral (silt or clay soils) to slightly acid (sandy soils) soil environment. However, under nearly all farming conditions a decline in soil pH occurs over time. This is due to leaching, soil respiration by microbes and plant roots, root excretion of organic acids and input of acidifying substances from the atmosphere (“acid rain”) or farm inputs (e.g. N fertilizers). Suboptimal soil pH values induce a general stress situation for plants (e.g. poorer root growth, increased uptake of phyto-toxic elements). Furthermore a decline in nutrient availability might occur (e.g. phosphate, an essential plant nutrient, might react with iron and/or aluminum oxides to non plant available compounds at low soil pH) and/or due to lower microbial activity in the soil the release of organically bound nutrients from soil reserves can be reduced. To adjust soil pH to the required level (depending on soil type and crop to be grown) regular application of lime is standard farm practice. In general liming is done every 3 - 5 years uniformly for a given field based on the soil pH measurements in the lab. However, in several studies it has been shown that soil pH might fluctuate considerably within a field even at short distances (e.g. Bianchini and Mallarino, 2002; McBratney and Pringle, 1997; Olfs et al., 2010; Borchert et al., 2011). Because the required density of soil pH data cannot be achieved by manual soil sampling due to time constraints and analysis costs for the vast number of samples reliable spatial information on soil pH was almost not available for farmers.

Since 2003 the automated system Veris MSP for mapping soil pH is available from Veris Technologies Inc. (Salina, KS, USA). This online pH sensor has been extensively validated under US farming conditions (e.g. Viscarra Rossel and McBratney, 1997; Adamchuk et al., 1999; Lund et al., 2005). At present reliable information on how to use Veris MSP data for decisions on liming rates under German conditions is not available. Therefore lab and field trials to evaluate the on-the-go pH measurement system were conducted in north-western Germany from 2009 to 2011.

MATERIALS AND METHODS

After adjustment to German farm technology a Veris MSP sensor system equipped with a pH and an EC unit (Fig. 1) was used to map 30 arable fields located in north-western Germany. Field size ranged from 2 to 45 ha and soil texture varied from sandy to loamy. Online pH-measurements were done at a speed of 5 - 13 km/h and spacing between passes of 7.5 - 30 m resulting in a sampling density of 30 - 90 samples per hectare. Generally for online pH-measurements the soil surface is cleared from crop residue and loose soil is compacted by a firming wheel. A sampling shoe is hydraulically forced into the soil (ca. 8 - 10 cm) creating a soil core which flows through the sampling shoe. Periodically this sampling unit with the soil core is lifted up against two antimony electrodes to measure the pH. If the difference between the readings of the two electrodes is smaller than 0.5 pH units (within a measuring time of 30 seconds), the average value is stored on a compact flash card together with the data for the georeferenced position. Thereafter the sampling shoe is pushed again into the soil. Meanwhile the electrodes are cleaned with demineralized water (electric conductivity < 12 mS cm^{-1}).

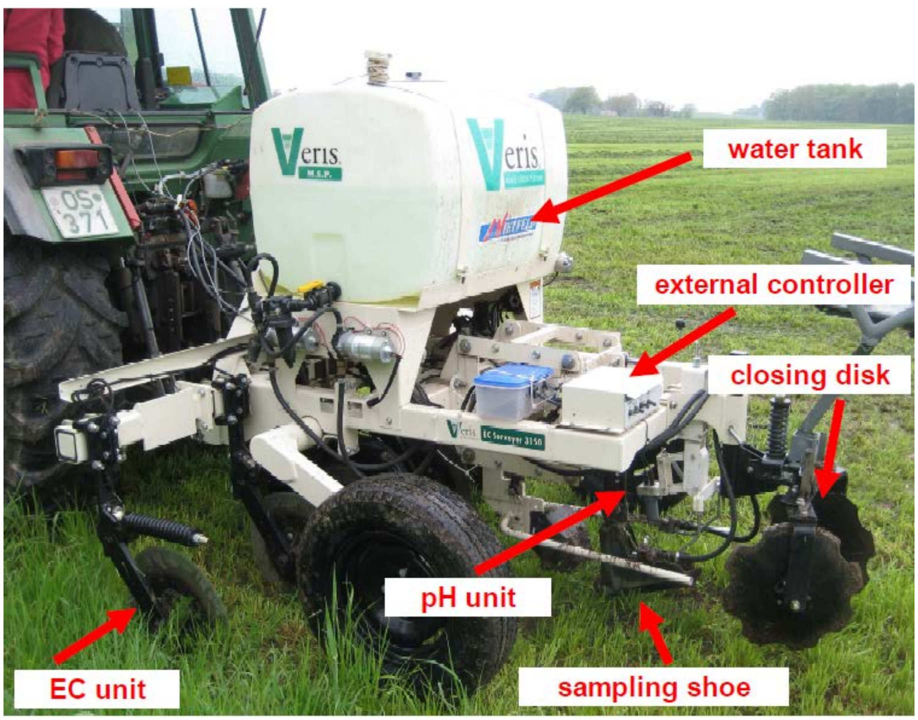

Figure 1. Set-up of the Veris MSP online pH mapping system

On 17 fields so-called reference samples were collected in zones with low, medium and high pH values (0 - 30 cm soil layer; 15 individual soil cores combined to one sample). To calculate representative Veris pH values for these reference samples online pH data within a radius of 15 meters around the sampling points were taken into account using the inverse distance method. The relationship between Veris MSP and lab data for these reference samples was assessed by regression analysis using reference sample data either from all study fields or from an individual field.

To evaluate the effect of a variable lime application strategy plot trials were conducted on a 7.1 ha field (soil texture loamy sand). Based on a Veris MSP pH map 5 different zones with pH values from 5.1 to 5.8 were identified. End of April 2010 in each zone 3 treatments were installed: (1) no lime [= "control"], (2) average lime rate based on the mean pH value for the field [= "field average"], and (3) adjusted lime rate based on the pH value of each specific zone [= "site specific variable"]. Maize was sown and during the vegetation period maize leaves were collected at tassling. The plant material was dried, homogenized and analysed for nutrient concentrations (N/P/K/S/Mg/Cu/Mn/Zn) according to standard lab protocols. After harvest soil samples were taken in each plot (0 – 30 cm).

All soils for lab pH measurement were homogenized, air dried, sieved (2 mm mesh) and analysed according to the German standard procedure (i.e. 0.01 molar $CaCl_2$ solution at a ratio of 1 : 2.5, 2 hours reaction time; VDLUFA, 1991).

RESULTS AND DISCUSSION

Irrespective of field size a considerable soil pH range (i.e. minimum versus maximum pH; disregarding outliers) was determined (0.9 - 3.1 Veris MSP pH units; Fig. 2) for all fields of this series. Based on calculations of interpercentil ranges (IPR_{90}; i.e. pH range for all samples without the 5 % lowest and 5 % highest values) it is obvious that in-field variability of soil pH is relevant to be considered for management adaptations for many fields. Even at small-scale variation in soil pH is detectable providing evidence that a high sampling density is required to derive reliable lime application maps (Olfs et al., 2010). This is in agreement with results reported from surveys conducted by Bianchini and Mallarino (2002), Brouder et al. (2005) and Lauzon et al. (2005) in North America.

To ensure acceptance by German farmers for site-specific lime application, recommendations have to be calculated on the basis of the well established system developed by the German advisory organization. However, the difference between Veris MSP and manual sampling/lab analysis pH values is quite substantial especially in low pH zones (e.g. Staggenborg et al., 2007; Olfs et al., 2010; Schirrmann et al., 2011). This can be explained due to the differences in the measurement procedure: a prolonged reaction period (ca. 2 hours) and the use of a 0.01 molar $CaCl_2$ solution as extractant initiates an increased desorption of H^+ ions from binding sites at soil particles resulting in lower pH value under lab conditions. According to Erickson (2004) on-the-go pH-measurement at field scale characterizes only the actual pH in the soil solution. Therefore Veris MSP pH values need to be converted before lime application maps can be generated.

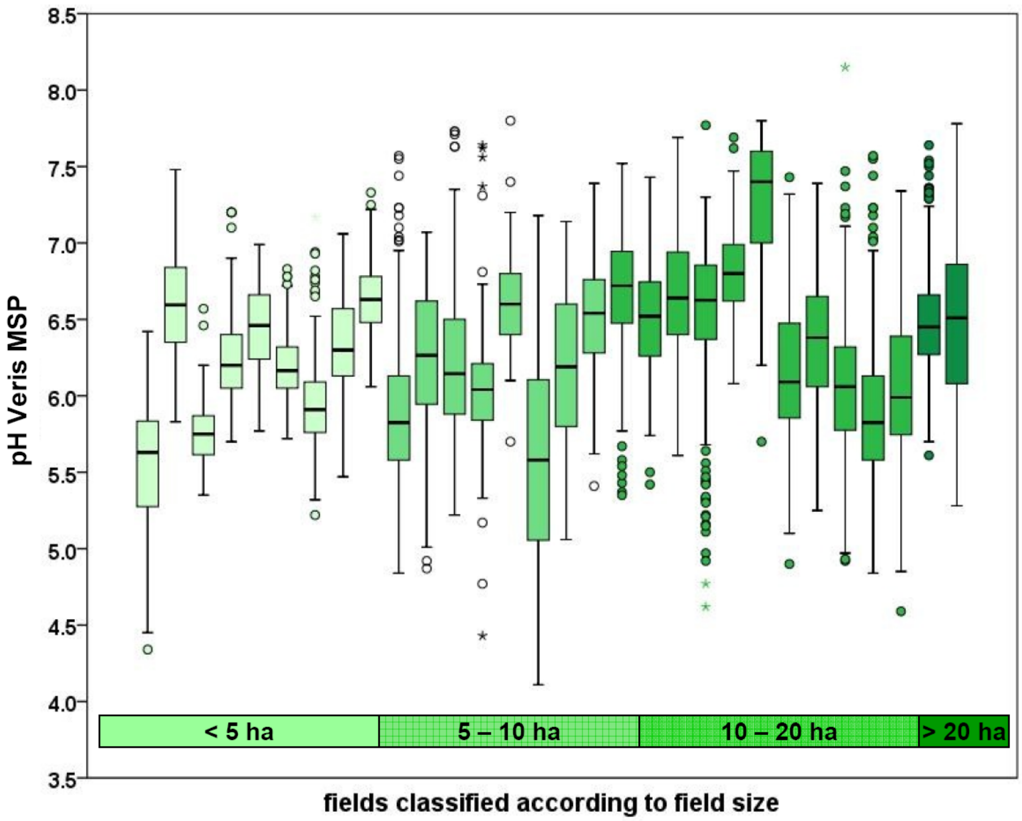

Figure 2. Veris MSP soil pH (median, interpercentil ranges for 50 % [boxes] and 75 % of the samples [vertical lines]) for 30 fields in north-western Germany (field size 2 to 45 ha)

The correlations between lab analysed reference samples and Veris MSP pH values were calculated in two different ways. In the first approach pH values were pooled for 51 data pairs (for each of the 17 selected fields three reference samples were collected). As an alternative calculation procedure only the pH values of the reference samples of each individual field were used as calibration set for the transformation of the Veris MSP values. As expected the differences between lab and recalculated Veris MSP pH values are observable smaller for both calculation procedures (Fig. 3). In the approach which includes all data-sets the averaged difference between reference pH values and Veris MSP values was 0.26 pH units, but still for several data-pairs the difference is greater than 0.5 pH units. For the re-calculation procedure which is based only on the 3 individual reference samples for a field the overall fit between the lab and transformed Veris MSP data-set is much better resulting in an average pH difference of 0.08 pH units. From these results it can be concluded that in principle the re-calculation of Veris MSP data into pH values conform to the German standard system seems possible using a general calibration equation. However, the comparability is substantially improved when reference samples from different pH zones of each individual field are used for the calculations. This procedure will also take other interference factors (e.g. changes in the signal strength from the electrodes due to abrasion/ deterioration, water quality, temperature) into account, which might alter the online pH measurement under field conditions.

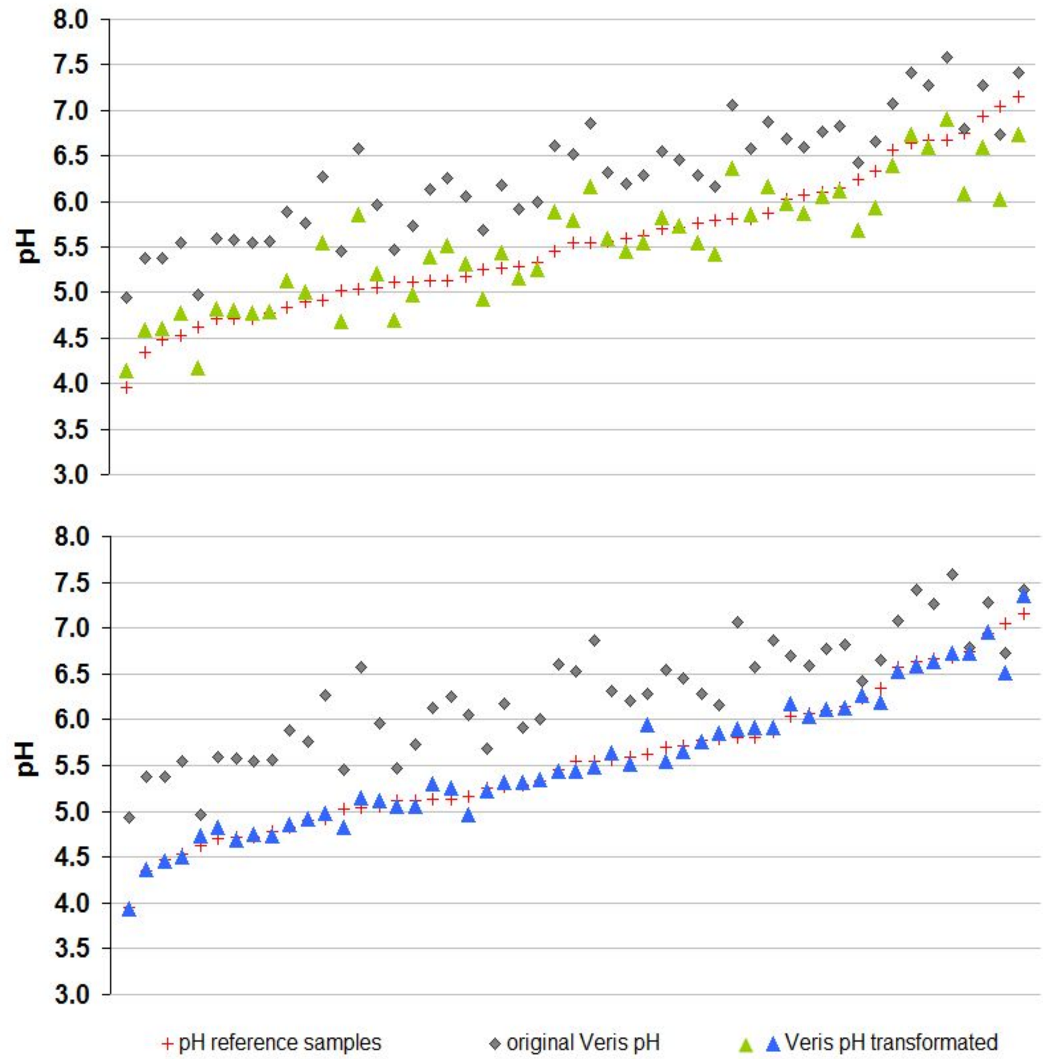

Figure 3. Lab pH values for reference samples, original Veris pH values and Veris data after transformation based on all 51 samples (top) and 3 individual reference samples for a field (bottom)

The impact of the 3 different liming strategies (no lime, field average, and site specific variable) on the N/P/K/S/Mg concentrations in maize leaves at tasseling growth stage was rather marginal (data not shown). Plant analytical results for micro nutrients which are considered as significative for maize show a different picture: While no differentiation occurred for copper, significantly higher leaf concentrations were found for manganese and zinc in the "no lime" treatment

(Fig. 4). It is well known that plant availability of these micro nutrients is clearly depending on soil pH, i.e. lime application will decrease concentrations in the soil solution and as a consequence absorption by plant roots will be hampered.

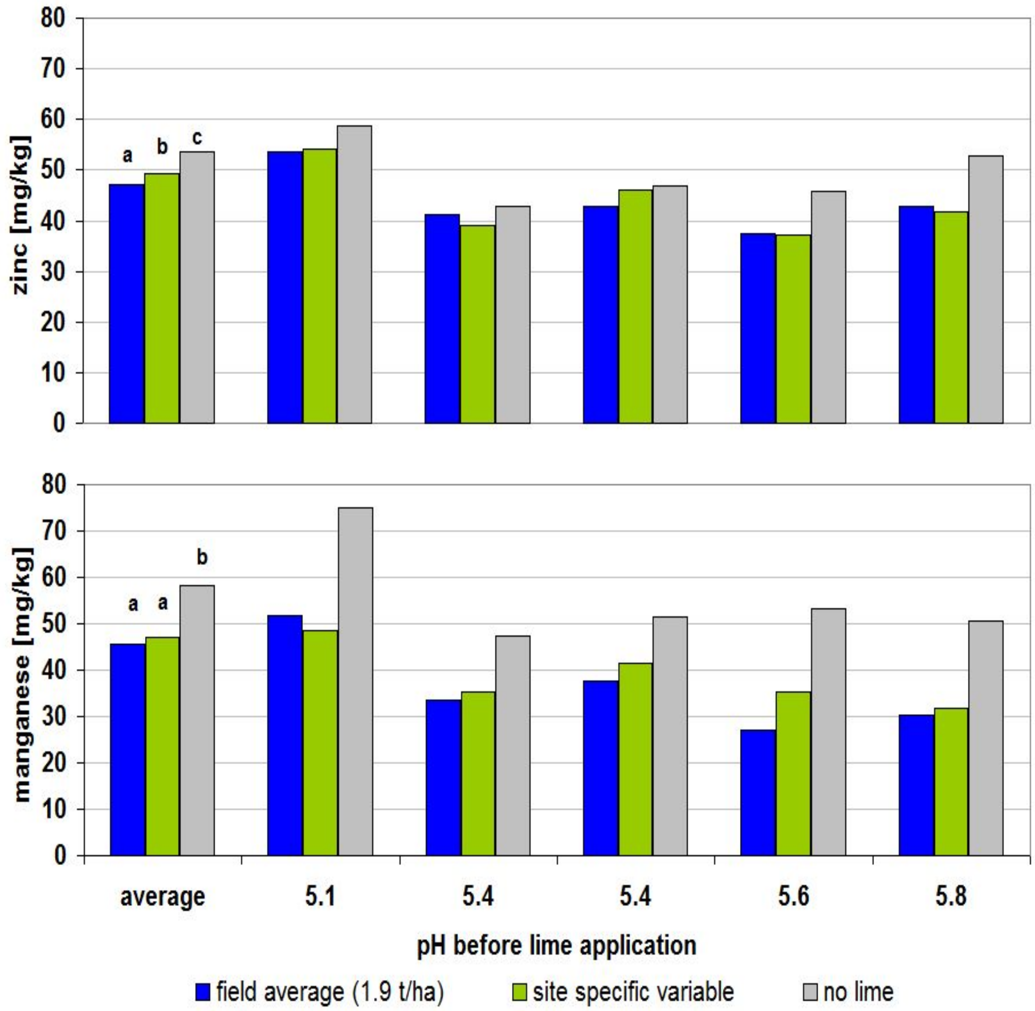

Figure 4. Zinc (top) and manganese (bottom) concentrations in maize leaves at tasseling growth stage for 3 different lime application strategies

Data on soil pH after maize harvest confirm this interpretation. On average for the 5 subplots the lowest pH value occur for the control treatment without lime application, while the average value for the "field average" and the "site specific variable" lime treatments are significantly higher compared to the control, but do not show significant differences between each other (Fig. 5).

Interestingly the individual data for the 5 subplots reveal that a uniform lime rate according to the average pH value of the field results in a distinct higher soil pH variability. At least for one subplot the target range for the pH values (5.5 – 6.2) is not achieved and for one subplot the pH value is at the upper limit. On the other hand soil pH values for the plots with lime application rates adopted to the soil pH of the individual plot are rather homogeneous and are all with in the recommended range for this soil type.

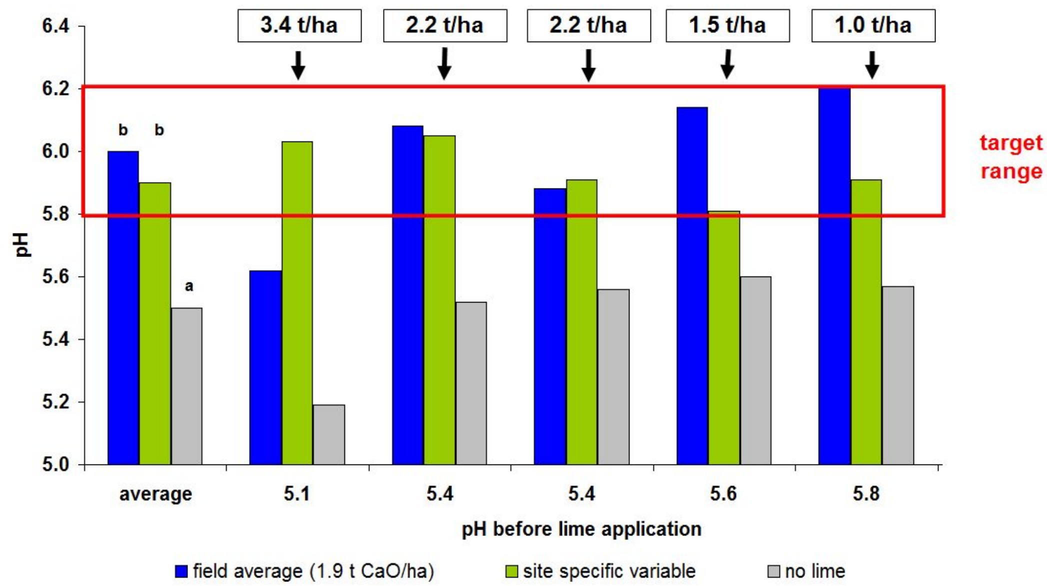

Figure 5. Soil pH in samples from different soil layers for 3 different fields

CONCLUSION

Data on in-field variability of soil pH for arable fields in north-western Germany obtained with the Veris MSP on-the-go system indicate that it is reasonable to adopt liming rates. Using reference samples for each individual field analysed in the lab according to the German standard procedure enables adequate transformation of the Veris MSP pH values so that the established lime recommendations can be applied. It can be expected that such a precise liming strategy will result in a more homogeneous soil pH status compared with standard farm practice and finally improve crop growing conditions.

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enable routine data management at field level to localize zones for reference sampling and for data exploration and visualization at office level.

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